Hot extrusion die design and process simulation of an unsymmetrical structure

Prof. **Jinn-Jong Sheu**, National Kaohsiung University of Applied Sciences, Kaohsiung, Taiwan

Mr. **Jia-Ming, Liang,** National Kaohsiung University of Applied Sciences, Kaohsiung, Taiwan

Abstract

In this paper, different die designs were proposed for hot extrusion of an unsymmetrical structure part. Three different guiding geometries of the extrusion die were designed for comparison of the material flow patterns. The design process and parameters of hot extrusion die were studied. The areas of die orifices were determined based on the geometrical features of the product to obtain uniform extrusion process. Finite volume method was adopted to simulate the hot extrusion process and verify the effects of the different guiding designs. Different mesh densities of billet were defined to save simulation time and improve the accuracy of simulation. The material flows of the exit product were constrained using dummy run out guidance to simulate the drawing device adopted in the hot extrusion process. The flow balance is difficult due to the thin and long leg, as a result, the exit profiles and the velocity distributions of the tip were dramatically uneven. The FVM simulation is capable of simulating the effect of die design and predicting the variation of exit profile. The material flow information is very helpful for the hot extrusion die design and the process control.

1. Introduction

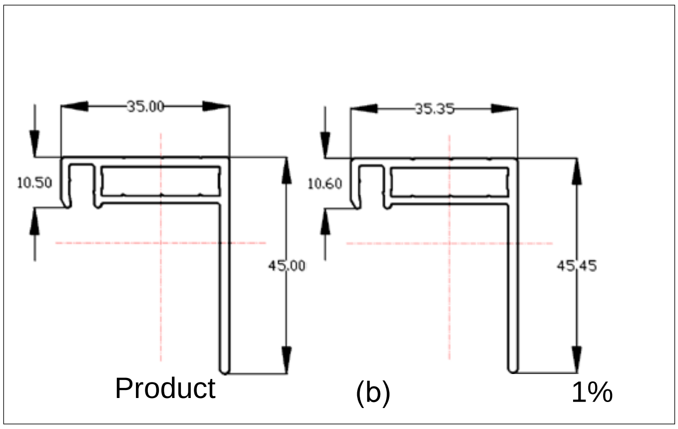
The simulations of hot extrusion process are very difficult due to the large deformation due to the billet separation in front of the male die(mandrel) and billet reunification in the welding chamber. Alfaro et. al[1] proposed a natural element method using α-shaped cloud nodes to approximate tetrahedron mesh for extrusion simulation. This method was adopted to solve the complex boundary contact and predict the material flow efficiently. Fang et. al[2] had studied the effects of different welding chamber design on the exit velocity uniformity for thin and large aspect ratio extruded parts. Some design rules was concluded for better exit velocity uniformity. Fang et. al[3] had studied the exit temperature variation for a complex product with large wall thickness variation along profile using 3D FEM simulation and experimental tests. The bearing design and the extrusion velocity were changed to control the exit temperature and obtain better surface quality of extrudate. Wu et. al[4] had applied the finite volume method(FVM) to predict the velocity flow of hot extrusion process. The flow channel geometry and location, and the size of welding chamber were changed to get better designs. Lou et. al[5] had adopted FVM with Euler mesh to simulate the 3D transition and steady state aluminum hot extrusion. The velocity and pressure fields were obtained using the semi-implicit algorithm (SLMPLE).

Ceretti et. al[6] had applied flat rolling experiments to simulate the welding phenomenon of hot extrusion. The proposed welding model of hot extrusion process was verified with industrial extrusion tests and showed good agreement. Zhang et. al[7] had studied the stem velocity effects on the temperature distribution, extrusion load, welding pressure for a hollow aluminum product. An optimum stem velocity was found to obtain better welding quality of the seamed lines of product. This paper adopted FVM simulation to evaluate the different extrusion die design. The exit velocity distributions and profiles were studied.

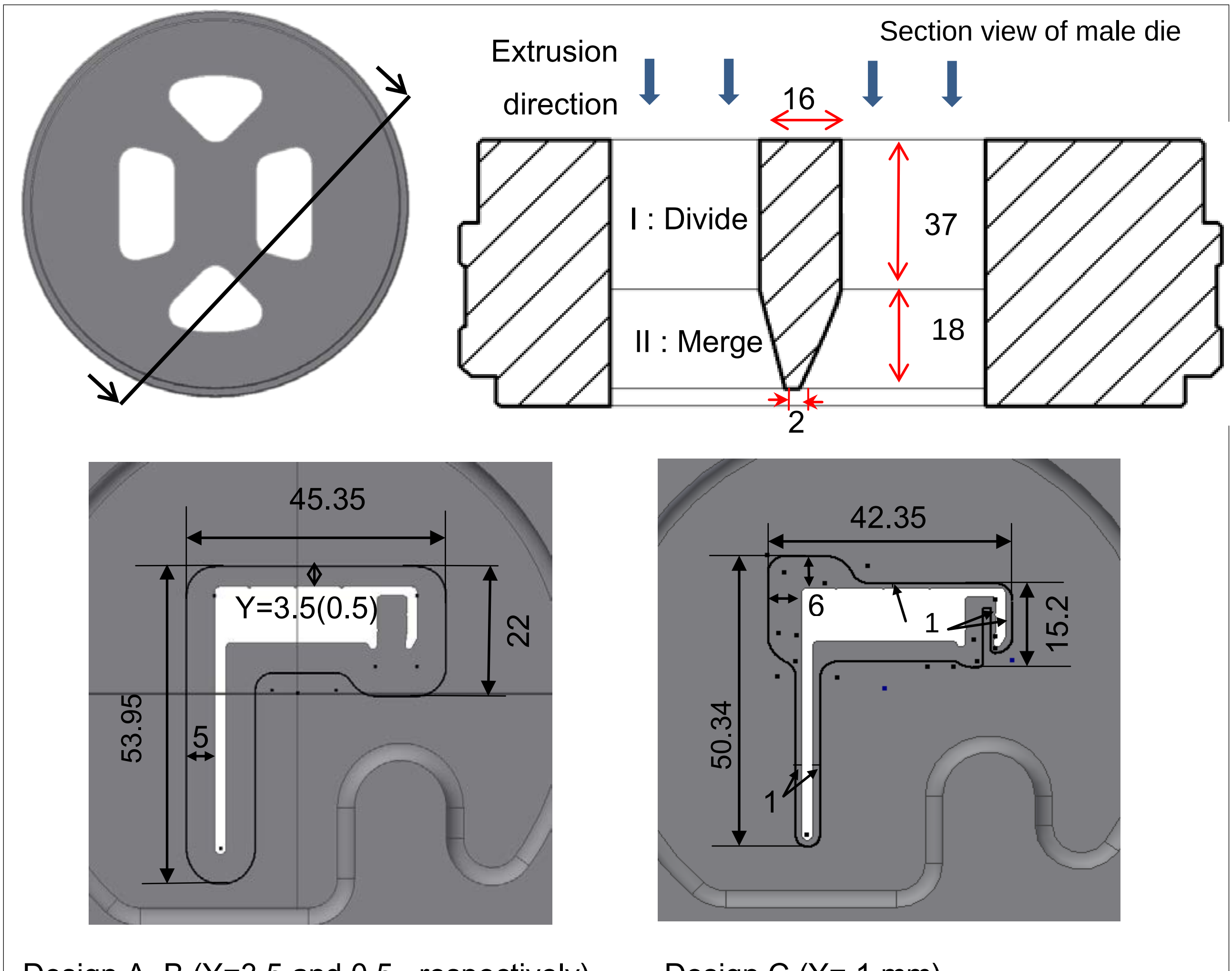
2. Extruded product and die design

The profiles of the extruded product were shown in Picture 1. The 1% shrinkage was considered because the hot expansion coefficient of aluminum 6061 T6 is 2.56×10^{-5} mm/(mm-C) and the billet temperature is 450 Celsius degrees. The thickness of the product is 2 mm. The four ports male die and female die were shown at the left and the right hand side of Picture 2, respectively. There are three different female die design proposed in this study. Design A, and B using straight offset at the guiding room with different top boundary offset (dimension Y) 3.5 mm and 0.5 mm, respectively. These two designs were proposed to study the effect of guiding room area size. Design C enlarges the offset distance at the top left corner area but reduce the offset distance at the top edge (dimension Y) to 1 mm. This design was adopted to study the influence of the different offset distances on the material flows. The isometric view of the proposed male dies (only design A was shown) and female die were shown in Picture 3.

Picture 1: Profiles of the extruded part (left) and 1% compensation (right).

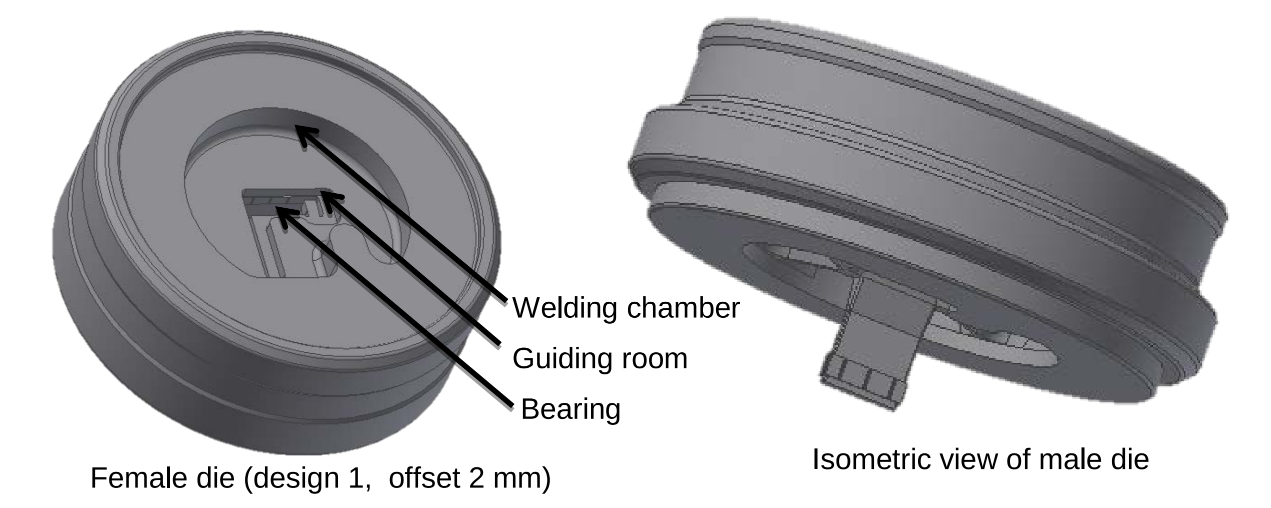


Picture 2: Design parameters for male die (top) and female die (bottom).



Design A, B (Y=3.5 and 0.5 , respectively) Design C (Y= 1 mm)

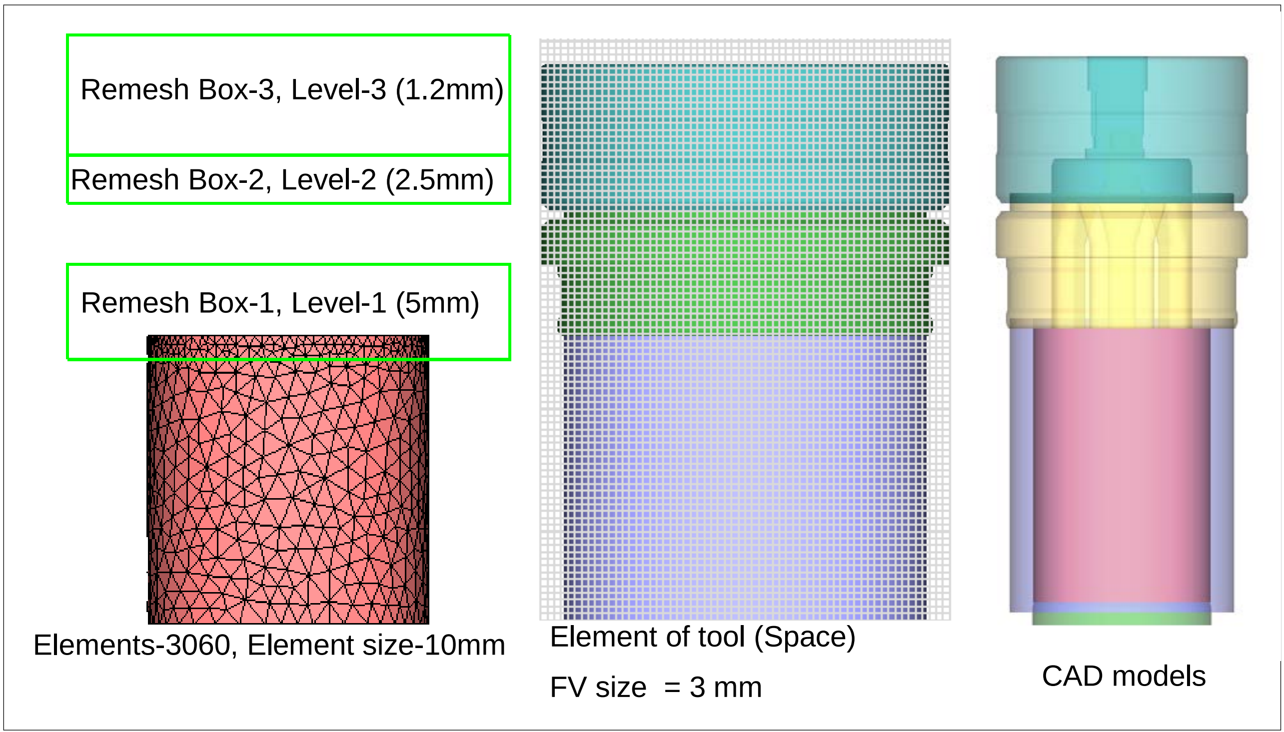
Picture 3: Isometric view of the designed female die (left) and male die (right).



3. FVM simulation of the hot extrusion process

The aluminium 6061 T6 billet diameter of this study in 5 inch and will be heated up to 480 degree C. The die temperature is 450 Degree C. The mesh of billet and tools for FV simulation and the CAD models were shown in Picture 4. Three remesh boxes were given to increase simulation precision.

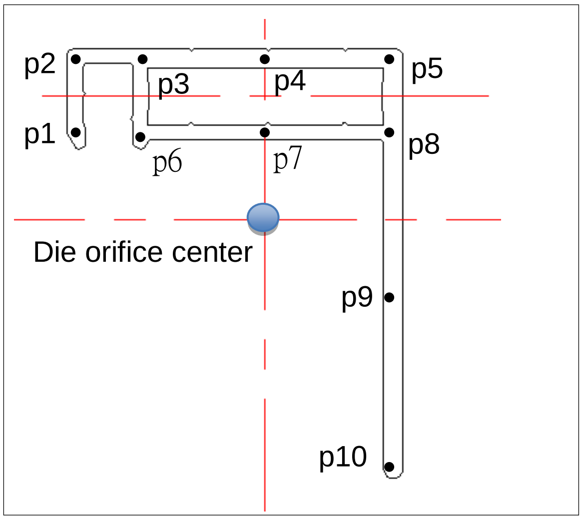
Picture 4: Profiles of the extruded part without and with shrinkage 1% consideration.



4. Results and discussion

Ten points on the exit front end were measured to check the uniformity of the exit velocity field. was measured to compare the uniformity of material flows for different die design. The measurement locations (P_1 to P_{10}) were shown in Picture 5 which demonstrates the relative relation between the centers of die orifice and product geometry.

Picture 5: Measurement points of the exit front end.



Design A : the exit velocity distributions and the geometry of the front ends of the extruded product for design A were shown in Picture 6 in different time of extrusion. At time 9.13 second, the extrudate was just out of the die orifice. Exit velocity of point 2 changed dramatically during the extrusion process that means uneven material flow occurred at this corner.

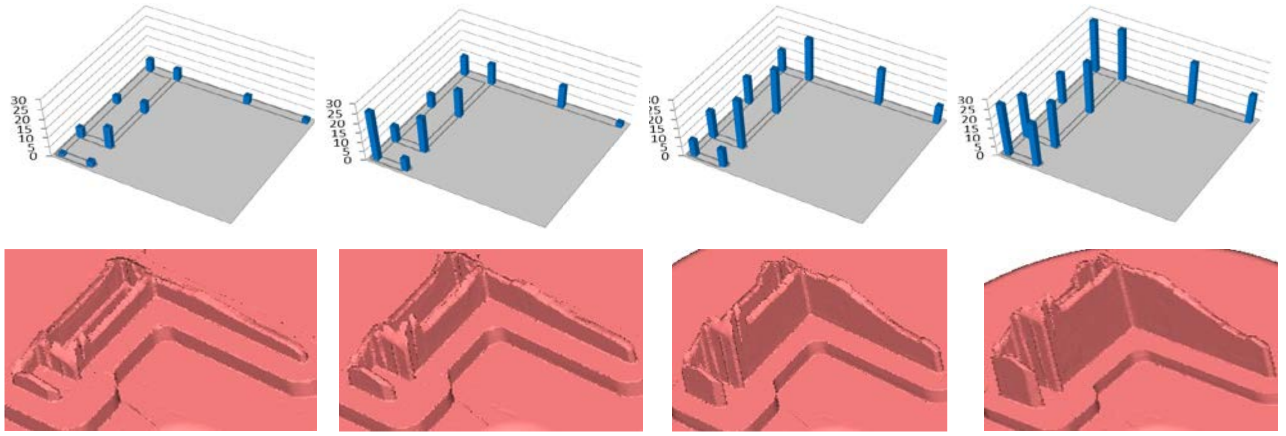
Design B : the exit velocity distributions and the geometry of the front ends of the extruded product for design B were shown in Picture 7 in different time of extrusion. Exit velocity of point 2 were not changed dramatically during the extrusion process that means even material flow occurred at this corner.

Design C : the exit velocity distributions and the geometry of the front ends of the extruded product for design C were shown in Picture 8 in different time of extrusion. Exit velocity of point 2 changed dramatically during the extrusion process that means even material flow occurred at this corner.

Extrusion Load: the history of extrusion load versus time stroke for three designs was shown in Picture 9. There are four significant forming stages: billet dividing, billet stream emerging, welding, and product run out. Stage 1 shows the characteristic of direct forward extrusion, the peak load indicates the billet was divided into four streams and entered zone I of male die shown in Picture 2.

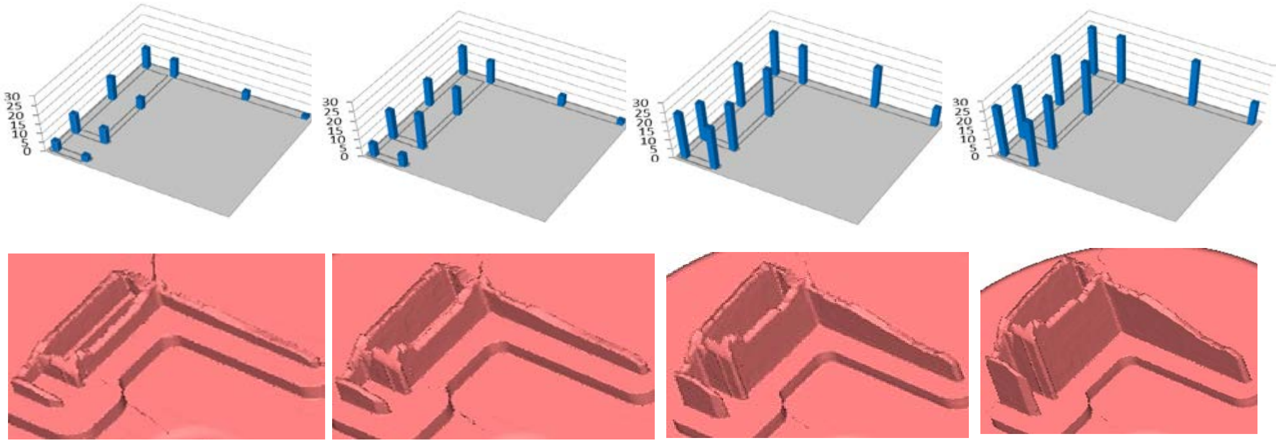
The extrusion load decreases due to the decreasing of friction force in container. Stage 2 indicates the materials were flowing into zone II of male die and four streams of billet were emerging to the welding chamber which is in front of the guiding room. The materials move freely so the extrusion load keeps almost constant. Stage 3 indicates the materials were flowing into guiding room and pressed further to obtain good welding strength. The extrusion load increases to push material forward into small guiding area. Stage 4 indicates the materials were flowing into bearing area and running out to give the section profile of the extruded product. The maximum loads were 606.7, 583.6, and 624.6 tons, respectively. From the view point of saving energy, design B is better for achieving uniform exit velocity and consuming lower energy.

Picture 6: Design A; Exit velocities and section profiles with respect to extrusion time.



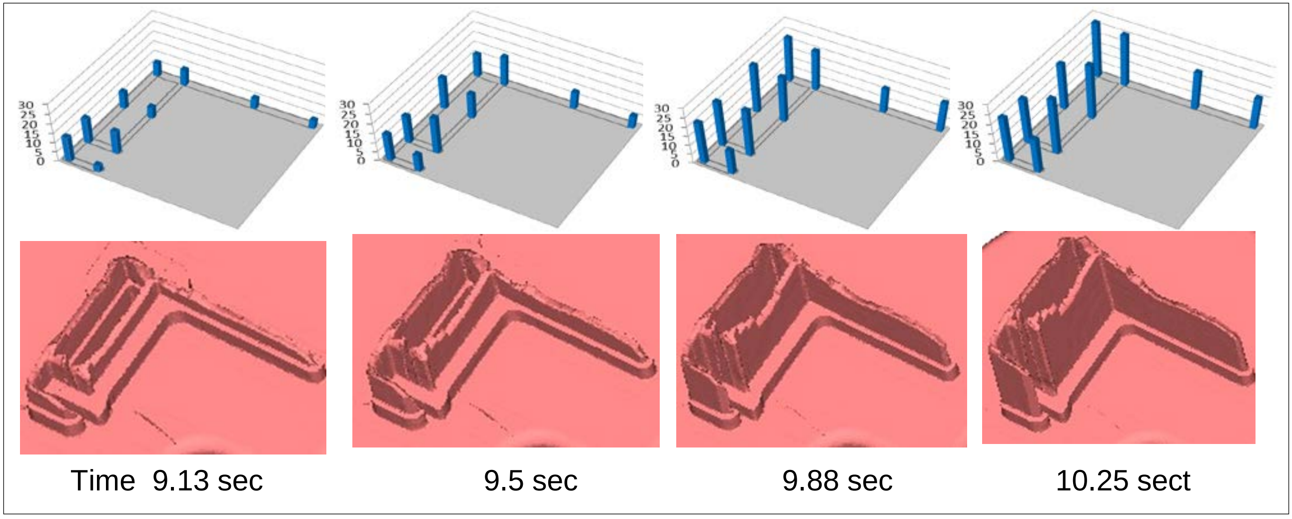
Time 9.13 sec | 9.5 sec | 9.88 sec | 10.25 sect

Picture 7: Design B; Exit velocities and section profiles with respect to extrusion time.

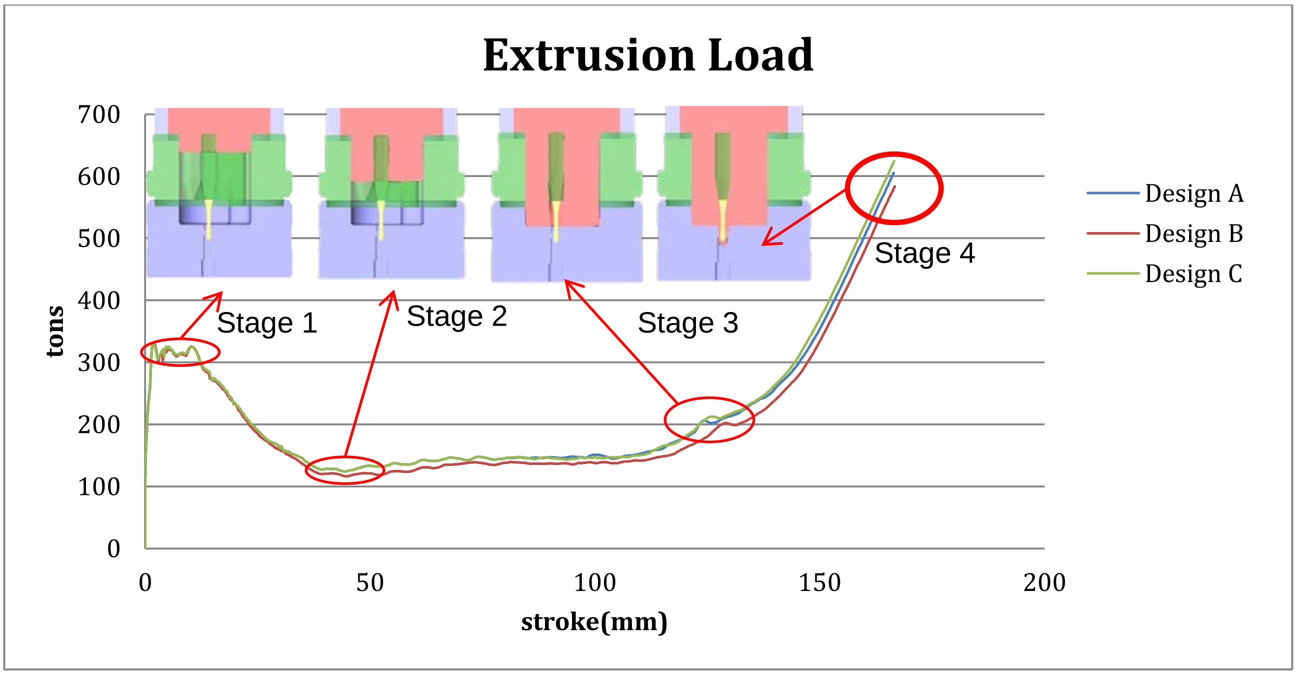


Time 9.13 sec | 9.5 sec | 9.88 sec | 10.25 sect

Picture 8: Design C; Exit velocity and shape of the extrudate for different extrusion time.



Picture 9: Design C; Exit velocity and shape of the extrudate front end for different extrusion time



4. Conclusions

The simulation results had demonstrated the different guiding room designs will change exit velocity field dramatically. While the history and maximum extrusion loads of different designs were not influenced significantly. The FVM was capable of simulating the complete hot extrusion process of aluminum 6061 T6 for this product. Further investigations are required to obtain better extrusion die designs.

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